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LECTURES

ON

EXPLOSIVES.

By

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The Lectures were given under a scheme the aim of which is to indicate to advanced students the scope and object of work actually carried out by professional chemists in various branches of practice. They were delivered before the Institute of Chemistry, at King's College, London (by kind permission of the Delegacy of the College), on February 26*th*, 1914, *Professor Raphael Meldola, President, in the Chair; and on March* 26*th*, 1914, *Professor Herbert Jackson in the Chair.*

SYLLABUS OF THE LECTURES.

Short historical sketch of manufacture and use of explosives. Comparatively little change or progress made until about fifty years ago; since then, great and varied development.

Field of available bodies and mixtures as explosives greatly widened by introduction of detonators.

General considerations of the character of explosive decompositions.

Two modes of explosion: Combustion or deflagration and Detonation. Means of initiating each mode.

Velocity of explosion wave in detonated explosives.

Conditions under which the result of an explosive decomposition can be foreseen from theory; conditions which interfere with theoretical conclusions and necessitate experimental determination.

Limitations of experimental methods.

Heat developed, volume and composition of gases and pressure produced. Effect of pressure on composition of gases.

Theoretical temperature reached on explosion. Experimental attempts to measure it. Need for further work.

Sensitiveness of explosives: means of increasing or diminishing it.

Consideration of certain types of explosives in general use.

Qualities which they should possess.

Methods of testing explosives.

General description of Rules and Regulations prescribed by the Explosive Department of the Home Office for the construction and working of explosive factories.

Description of processes and plant used in the manufacture of the principal explosives.

Military propellants and the conditions which they have to fulfil.

Sporting powders: General characteristics.

"Permitted" explosives for use in fiery coal mines, and the Home Office Test which they have to pass.

Recent filling material for shells.

Novel application of explosives.

Scope of the chemist's work in connection with explosives.

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Blast at Lord Penrhyn's Slate Quarries.

Lecture I.

Most men, whatever branch of work in life they may now be pursuing, have, as boys, had some practical acquaintance with explosives, often of an astonishing and painful nature; so that one may assume among those present at least an elementary familiarity with some form or other of explosive.

The late Oscar Guttmann has shown conclusively, I think, that the invention of black gunpowder was due to Roger Bacon in the thirteenth century, and since that time man has always been endeavouring to make explosives do work for him, either by way of driving bullets out of guns and bursting shells, or of blasting rocks which hindered him in engineering or mining work.

In regard to the former use of gunpowder, Carlyle in "Sartor Resartus" makes Teufelsdroeck say, after he has repulsed a huge ruffian by confronting him with a loaded pistol, "Such I hold to be the genuine use of gunpowder that it makes all men alike tall. Nay, if thou be cooler, cleverer than I; if thou have more Mind, though all but no body whatever, then thou canst kill me first, and art the taller. Hereby at last is the Goliath powerless, and the David resistless; savage animalism is nothing, inventive spiritualism is all."

Whatever opinions may be entertained as to the use of explosives in war, the cartridge of *blasting* explosive is indeed a beneficent Thor's hammer which lightens and expedites the work of the civil engineer and miner to an enormous extent.

An explosive is a body which under the influence of heat or shock, or both, is, speaking popularly, instantaneously resolved entirely, or almost so, into gases.

The kinds of explosives we are going to consider are those which either as single chemical bodies, or as mixtures of several, can be rapidly resolved into gases occupying at normal temperature and pressure many hundred times the volume of the original explosive. Consequently, at the very high temperature of explosion, these gases exert an enormous pressure which does work either in disrupting the body in which the explosive has been fired, as in the case of a rock or of a military shell, or by driving a projectile out of a gun.

We shall not discuss explosive systems which depend on *air* as an ingredient, such as mixtures of fire-damp, coal-dust, or flour and air.

It is a far cry from the early days when gunpowder was first used in war to the present highly developed and specialised manufacture of explosives. In the greater number of explosives, explosion may be regarded as more or less rapid combustion, generally of carbon and hydrogen with liberation of nitrogen. In the case of black powder, which is composed of potassium nitrate, 75 per cent., charcoal, 15 per cent., and sulphur, 10 per cent., the last named also takes part and adds to the complexity of the final products. The reactions involved are very complicated, and we are indebted to the classical researches of Noble and Abel for a knowledge of the products of decomposition of fired gunpowder. It is remarkable that the composition of black powder for guns has little altered from the earliest times, and comparatively slight improvements were made until about forty years ago, when the introduction of much larger guns made it desirable to have an explosive which would be slower in its action, evolve less heat, exercise less pressure in the chamber of the gun, and continue the driving power up to the issue of the projectile from the muzzle. This was attained partly by compressing the powder into large and dense prisms, by using partially

charred wood which still contained some water, and by decreasing the sulphur. This was known as cocoa, or brown prismatic powder, and gave, in larger guns, much better ballistic results than the black powder previously employed.

The discovery of guncotton which, as you know, is cotton waste treated with nitric and sulphuric acids, led to many attempts, especially in Austria, to utilise it as a propellant powder and for other purposes, but its purification was so difficult, and there were so many serious accidents with it, that little progress was made until Abel, in England, devised the process of treating the nitrated cotton in a paper pulping engine, whereby the fibres were reduced to an extremely fine state of division. This permitted the acids to be thoroughly washed out of the guncotton and a sufficiently stable material to be produced which was used with great success as a disruptive explosive for military purposes. It is also used as the bursting charge for torpedoes. When guncotton is saturated with water it cannot be exploded in the ordinary way and is therefore quite safe in handling and storage; but it was found that it could be exploded with full force by exploding a primer of dry guncotton in contact with it. This made guncotton a very safe and practical explosive from the military point of view.

Numerous attempts were made to utilise guncotton or other forms of nitrocellulose as a propellant, but powders made with it were very uncertain and often gave pressures which burst the guns.

Practically no further progress was made in powder for guns until W. F. Reid produced a sporting powder consisting of partially gelatinised nitrocellulose and barium nitrate. Soon afterwards Vieille, in 1884, produced the first really smokeless powder from gelatinised nitrocellulose, the French service "Poudre B." A little later Alfred Nobel succeeded in forming a safe and efficient propellant by dissolving or gela-

tinising nitrocotton in nitroglycerine and producing a hard horn-like body which could be cut into any suitable form. This he called ballistite.

Once the way was shown of safely using nitrocellulose alone or with nitroglycerine as a propellant, developments and modifications rapidly followed, and the British service cordite, composed of nitroglycerine, guncotton, and mineral jelly, came into existence.

The results with these gelatinised powders showed that combustion proceeded regularly from the surface, and that when carefully made they could be relied upon to give uniform pressures and velocities.

It is very remarkable that nitroglycerine and guncotton, which are among the most sensitive, violent, and strongest of explosives and which, previous to the discovery of the restraining influence of hard gelatinisation, had proved far too violent for use in firearms, when united and gelatinised into a comparatively hard material, were completely tamed and gave out their great power in the most docile and satisfactory manner.

Turning from the military use of explosives, Nobel was the first to apply nitroglycerine as a blasting explosive. He began manufacturing it in Sweden, then came to Scotland, where the works at Ardeer were soon started. At first, the nitroglycerine was sent out in the liquid form and a sufficient quantity poured into the borehole. He tried to lessen the danger attending its use in this form by dissolving it in methyl alcohol. This certainly rendered the transport safer, but before the nitroglycerine could be used it had to be precipitated from the solution by the addition of water, and then used in the liquid form as before. There were, unfortunately, so many terrible accidents during its use that, for a time, its employment was prohibited in many European countries. Nobel solved the difficulty by absorbing the nitroglycerine in kieselguhr, an infusional earth, producing a semi-plastic body

in which form it could be transported and used with sufficient safety.

It is worthy of note that in the early days of nitroglycerine an American engineer, Mowbray, who had contracted to make the Hoosac tunnel, made nitroglycerine in sufficient quantity for his own purposes and transported it from the works to its place of employment in the frozen state, in which case the danger from leakage was avoided. When frozen, nitroglycerine is more difficult to explode.

Kieselguhr dynamite cannot be considered an ideal explosive, because 25 per cent. of its weight consists of kieselguhr which acts solely as an absorbent and has no explosive power, and secondly because nitroglycerine contains about 3·5 per cent. more oxygen than is required for the complete oxidation of the carbon and hydrogen which it contains.

Again Nobel was successful, in producing blasting gelatine, which is a stiff jelly-like body formed by dissolving about 7 per cent. of nitrocotton in nitroglycerine by the aid of gentle heat. This is the most powerful explosive in use. It has an extremely shattering action, and is only used in the hardest rocks; indeed, it is too strong for many kinds of work. Various forms of less violent explosives are made by incorporating with a thin jelly of nitroglycerine and nitrocotton, wood meal, and potassium nitrate, these being known under the names of gelatine dynamite, gelignite, etc.

A large number of bodies and mixtures were made available for explosive purposes, when Nobel discovered that many mixtures which could not be brought to explosion by ignition could develop their full force when fired by a detonator.

Sprengel showed that compounds capable of internal combustion and mixtures of oxidising and combustible ingredients could be exploded by means of a detonator. From Sprengel's work arose the large number of so-called "Safety Explosives" which consist principally of nitrocompounds of the aromatic

class, such as dinitrobenzene, trinitrotoluene, etc., and ammonium nitrate.

Reference has been made to detonators. These are small copper tubes containing a charge of mercury fulminate either alone or, more usually, mixed with potassium chlorate or other ingredients. The charge of material in the most generally used detonators is one gram, although larger and smaller detonators are made for special purposes.

Chlorates, and latterly perchlorates, have possessed great attraction for the inventor of explosives, but it is only recently that mixtures containing potassium chlorate have been produced sufficiently safe in character to receive the authorisation of the Home Office to be manufactured and used.

Having thus taken a rapid and general review of the history of explosives it will be well to consider some of the principles underlying explosive decompositions, and the manufacture of explosives.

Practical explosives consist either of bodies such as nitroglycerine and nitrocellulose, which are explosive in themselves, or mixtures of ingredients which separately are, or may be, non-explosive, but when intimately mixed are capable of being exploded.

Explosives are exploded either by simple ignition, as in the case of black gunpowder, or by means of a detonator containing mercury fulminate.

Explosive science owes an immense debt of gratitude to Berthelot. Already a distinguished chemist, he made his first practical acquaintance with explosives when, being shut up in Paris during the siege of 1870, he was appointed a member of the committee of defence, and had to do with the preparation of explosives in the beleagured city. His attention having been thus directed to explosives, when peace came, he began seriously to study the subject and, finding an almost complete

absence of what he considered necessary thermochemical data of bodies employed or capable of being employed in connection with explosives, he set to work experimentally to supply this knowledge which he finally embodied in his well-known book " Sur la force des matières explosifs d'après la thermo-chimie." I had the advantage of translating this work in collaboration with C. N. Hake, under the title of " Explosives and their Power."

Berthelot shows that the heat liberated by any explosive reaction, when both the mass and the constitution of the products of the reaction are known, can be calculated, as it is known that the heat liberated by a change of chemical condition in a system, is equal to the excess of the heat of formation of the final products, over the heat of formation of the initial products.

In the case of nitroglycerine, when it is exploded the products are all fully oxidised ; indeed, there is an excess of free oxygen, so it is a good instance for showing the method of calculation of the heat produced. The following formula shows the explosive decomposition :—

$$2(C_3H_5N_3O_9) = 6CO_2 + 5H_2O + 3N_2 + O.$$

From thermochemical tables it is found that the heat disengaged by the union of $C_3 + H_5 + N_3 + O_9 = C_3H_5(NO_3)_3$ liquid, amounts to 98 cals.

On the other hand, the formation of the products

$3(C + O_2) = 3CO_2$ disengages		$+ 94 \times 3 = 282$
$\frac{1}{2}[5(H_2 + O) = 5H_2O]$	„	$+ 34{\cdot}5 \times 5 = 172{\cdot}5$
	Total	454·5

The heat disengaged by the explosion will therefore be

$$454{\cdot}5 - 98{\cdot}0 = 356{\cdot}5 \text{ cals.}$$

This is the heat set free by the decomposition of one equivalent 227 grams of nitroglycerine, under atmospheric pressure about the temperature of 15° C.

Table I.—Indicating the Quantity of Heat, also the Volume and Analysis of the Gas developed per Gramme with Nitroglycerine, Nitrocellulose, and with several different Combinations of these two Explosives made at Ardeer Factory.

	Composition of Explosive.	Calories per gramme.	Permanent gas.	Aqueous vapour.	Total volume of gas, calculated at 0° and 760 mm.	Per Cent. Composition of Permanent Gases.						Coefficient of potential energy.
						CO_2	CO	CH_4	O	H	N	
			Cubic centimetres per gramme.	Cubic centimetres per gramme.	Cubic centimetres per gramme.							
A.	Nitroglycerine . . .	1,652	464	257	741	63·0	—	—	4·0	—	33·0	1,224
B.	Nitrocellulose (N = 13·30 per cent.)	1,061	673	203	876	22·3	45·4	0·5	—	14·9	16·9	929
C.	50 per cent. nitrocellulose (N = 12·24 per cent.) 50 per cent. nitroglycerine	1,349	568	249	817	36·5	32·5	0·2	—	8·4	22·4	1,102
D.	50 per cent. nitrocellulose (N = 13·30 per cent.) 50 per cent. nitroglycerine	1,410	550	247	797	41·8	27·5	0·0	—	6·0	24·7	1,124
E.	80 per cent. nitrocellulose (N = 12·24 per cent.) 20 per cent. nitroglycerine	1,062	675	226	901	21·7	45·4	0·1	—	15·7	17·1	957
F.	80 per cent. nitrocellulose (N = 13·30 per cent.) 20 per cent. nitroglycerine	1,159	637	227	864	26·6	40·8	0·1	—	12·0	20·5	1,001
G.	35 per cent. nitrocellulose (N = 13·30 per cent.) 5 per cent. vaseline 60 per cent. nitroglycerine	1,280	627	236	863	26·7	39·8	0·5	—	12·8	20·2	1,105

If the decomposition take place in a closed vessel under constant volume, rather more heat will be set free, because the gases developed by the nitroglycerine in the open air perform a certain amount of work in driving back the atmosphere, and this work consumes a corresponding amount of heat.

TABLE II.—SHOWING THE HEAT DEVELOPED BY EXPLOSIVES CONTAINING NITROGLYCERINE AND NITROCELLULOSE IN DIFFERENT PROPORTIONS.

COMPOSITION OF EXPLOSIVE.			Calories per gramme.
Nitrocellulose (N = 13·3 per cent.).		Nitroglycerine.	
100 per cent. (dry pulp)		0	1,061
100 ,, (gelatinised)		0	922
90 ,,		10 per cent.	1,044
80 ,,		20 ,,	1,159
70 ,,		30 ,,	1,267
60 ,,		40 ,,	1,347
50 ,,		50 ,,	1,410
40 ,,		60 ,,	1,467
0 ,,		100 ,,	1,652
Nitrocellulose (N = 12·24 per cent.).		Nitroglycerine.	
80 per cent.		20 per cent.	1,062
60 ,,		40 ,,	1,288
50 ,,		50 ,,	1,349
40 ,,		60 ,,	1,405
Nitrocellulose (N = 13·3 per cent.).	Vaseline.	Nitroglycerine.	
55 per cent.	5 per cent.	40 per cent.	1,134
35 ,,	5 ,,	60 ,,	1,280

I shall not trouble you with the calculations involved—these can be found in Berthelot's and other works—but will merely say that under constant volume the above amount of heat would be increased from 356·5 to 360·6 cals., therefore one gram

will give 1,590 cals. This figure has been closely confirmed by measuring the heat disengaged by the explosion of nitro-glycerine in the calorimetric bomb, which affords an excellent means of measuring the heat evolved. The products yielded by an explosive can afterwards be determined.

The molecules of an explosive may be regarded as in a state of unstable chemical equilibrium. A stable state of equilibrium is brought about by the sudden decomposition of the original compounds with the evolution of heat. An explosion is thus an extremely rapid decomposition, accompanied by the production of a large volume of gas and the development of much heat.

There are two well-defined modes of explosion which can be described as combustion and detonation. In the former case, the explosive is simply ignited and combustion takes place by transference of heat from layer to layer of the explosive. The rapidity with which the combustion proceeds depends not only on the physical form of the explosive but also on the pressure under which the decomposition takes place. When in the form of fine grains, combustion proceeds much more quickly than when the grains are large, and the powder maker takes advantage of this fact in preparing powder for rifle and the various sized large guns.

Detonation on the other hand has to be started by a sufficiently strong impulse, such as the explosion of a charge of mercury fulminate ; it proceeds much more rapidly and is due to the formation of an explosion wave which has a velocity of thousands of metres per second.

Black gunpowder and allied explosives, as well as the smokeless powders, belong to the first or combustion class, and they are commonly designated "low" explosives.

"High" explosives indicate those, such as dynamites and nitrate of ammonia explosives, which detonate and have a greater shattering action than the former.

In regard to the velocity of the explosion wave, experiments have shown that its velocity in *gases* is dependent only on the nature of the gas and is not influenced by pressure. The velocity of the explosion wave for $H_2 + O$ is 2,810 metres per second.

The case is quite different, however, with *solid* and *liquid* explosives, where the velocity of detonation is not only dependent on the nature of the explosive but also when exploded in the open air, on the diameter of the cartridges used. When confined, the velocity increases with the pressure. Although there is this broad distinction between combustion and detonation, many high explosives such as the dynamites, when ignited, burn slowly, but this slow combustion may become more rapid and develop into detonation.

Dynamite has given a velocity of 6,000 metres, and picric acid 7,700 metres, per second.

It is impossible experimentally to study the effect of pressure on the compositions of the gases from explosives of high specific gravity when *fired in their own volume*, for no apparatus could be made to stand the pressure.

Sarrau has shown that, at constant temperature, the volume of the gases from explosion only diminishes by pressure up to a certain point, which is about $\frac{1}{1000}$ of the volume at normal temperature and pressure. The molecules of the gas are then supposed to be in contact with each other and cannot be further compressed. This is called the covolume, and, with explosives of high specific gravity, it means that the products of explosion in their most highly compressed state occupy a greater volume than the original explosive. The pressure of the gases would therefore be infinitely great, and no vessel could retain them. Still by using very strong bombs and the copper crusher gauge, and high density of charge, very high pressures have been successfully measured and much useful information obtained.

The volume and composition of the gas produced, both in regard to the power of the explosive and, in the case of mining explosives, the health of the miner, are of great importance. These gases are largely determined by the original composition of the explosive.

With an explosive like nitroglycerine, which contains more oxygen than is necessary for complete oxidation of the carbon and hydrogen, or where there is just sufficient oxygen for this purpose, the composition of the gases can be accurately foreseen. All the carbon is converted into carbon dioxide, the hydrogen into water, and the nitrogen is set free. It may be taken that in all cases of proper explosion, oxides of nitrogen are never produced.

When there is insufficient oxygen for complete oxidation, the products are carbon dioxide, carbon monoxide, hydrogen, water, and nitrogen, but the relative proportions vary with the pressure developed. When such an explosive is fired in a closed vessel under different densities of charge, that is, different quantities of explosive in the same volume, the volume and composition of the gas varies with the pressure developed by the explosion. The carbon dioxide and hydrogen increase and the carbon monoxide and water diminish as the pressure increases; also, at high pressures, considerable amounts of methane are formed. In the foregoing, it has been assumed that complete explosive decomposition has taken place.

When a high explosive burns, instead of explodes, the chemical changes are not only very much slower and the disruptive effect practically *nil*, but the character of the gases is entirely changed, large volumes of poisonous nitrous fumes along with other gases being produced.

The temperature developed by an explosive is of importance, because the higher the temperature the greater the erosion of the guns.

The formula

$$t = \frac{Q}{c},$$

where Q = the calories set free and c = the mean specific heat of the gases, should give the theoretical temperature developed by an explosive. One of the difficulties, however, in applying this formula is the lack of knowledge of the specific heats of the gases at these very high temperatures, and also of the degree of dissociation obtaining at the moment of maximum temperature. From experiments on the pressure of explosion, Mallard and Le Chatelier have determined the specific heats of the gases involved, and these values are now generally adopted when making calculations of the theoretical temperature.

Some years ago, I carried out a long series of experiments to measure directly the temperature developed during the explosion of various explosives in a closed vessel; but while the method adopted enabled the relative temperature to be measured with fair accuracy, much work remains to be done before the actual temperature can be experimentally ascertained. A rhodium-platinum wire couple was arranged in a Berthelot bomb and the current due to the temperature was registered by the deflection of a beam of light from a d'Arsonval mirror galvanometer—the higher the temperature the greater the deflection.*

In this way a close agreement was found between the deflections due to the temperature and the calories evolved.

Attempts to measure the temperature have also been made by Sir Andrew Noble, by placing osmium inside a bomb in which a large quantity of guncotton was fired under high density of charge, and he concluded from the appearance of the osmium after the explosion that the temperature reached had been much above the melting point of that metal, viz.,

* Proc Roy. Soc., Vol. 66, p. 221; J. S. C. I., 23, p. 298.

Relation between Heat of Explosion and Measured Temperature Rise.

------		Heat of explosion in calories.	Deflection of the galvanometer needle in millimetres.
Nitrocellulose powder	Containing saltpetre	742	106
		745	123
		755	135
		762	136
		786	137
		807	139
	Free from saltpetre	845	150
		896	160
		1,014	161
Nitroglycerine powder		1,031	168
		1,253	191
		1,286	204

Specific Volume, Calculated Temperature of Explosion and Characteristic Product for several Explosives.

No.	Explosive system.	Specific volume L.	Calculated temperature of explosion, °C.	Characteristic product.	
				$V_o \cdot Q$.	Relative value.*
1	Explosive gelatine (7 per cent. collodion) . .	710	3,540	1,164,000	100
2	Nitroglycerine . . .	712	3,470	1,125,000	97
3	Nitromannite . . .	723	3,430	1,099,000	95
4	Dynamite (75 per cent.) .	628	3,160	810,000	70
5	Nitroglycerine powder (40 per cent.) . . .	840	2,900	1,084,000	93
6	Guncotton (13 per cent. N.)	859	2,710	945,000	81
7	Guncotton powder . .	830	2,400	747,000	64
8	Collodion cotton (12 per cent. N.) . . .	974	1,940	711,000	61
9	Ammonium nitrate explosive (NH_4NO_3 with 10 per cent. of nitronaphthalene)	925	2,120	860,000	74
10	Picric acid . . .	877	2,430	710,000	61
11	Black powder . . .	285	2,770	195,000	17
12	Ammonium nitrate . .	937	2,120	590,000	50
13	Mercury fulminate . .	314	3,530	129,000	11

* Explosive gelatine counted as 100.

2,500° C. Similarly, when carbon rods were placed among a charge of cordite, diamonds were found, after the explosion, showing that the temperature had exceeded 4,000° C., the melting point of diamonds.

Experiments have also been made by allowing the gases to escape from the explosion chamber through a narrow orifice and measuring the amount of erosion produced, this served to indicate the relative temperature, as the erosion increases with the temperature.

The sensitiveness to explosion by heat or shock is also an important point, and it is found that the more sensitive an explosive, the less the energy required to bring about the explosion. Other things being equal, the sensitiveness of explosive substances increases with the heat developed by the explosive reaction.

Some bodies, such as nitrogen chloride and iodide, and the diazo compounds, are so extremely sensitive that no practical use has been made of them. Others, such as mercury fulminate, have found a regular use on account of their specific properties, although their manipulation demands the greatest care.

The sensitiveness of an explosive to shock or friction can be increased by admixture with sharp edged bodies like sand or ground glass, and decreased by the addition of fatty bodies.

After this general survey of explosives and the phenomena of explosion, we shall now consider more particularly certain types of explosives in general use at the present time.

In coming now, as it were, into touch with concrete explosives, it may be well to insist on the necessity for the exercise of the greatest care in working with them, and not to allow familiarity to breed contempt. It is always well to bear in mind the cautionary advice of the late Colonel Cundill, " Remember, the chief function of an explosive is to explode ! "

It is worth mentioning that the late Alfred Nobel was one of the most careful workers I have ever seen.

Black gunpowder, although it has practically ceased to be used as a military propellant, is still largely employed for blasting purposes and, in this field, it has special properties which cause it to be selected in preference to all others for certain work. For instance, if the blast is to win the stone in large blocks, as in a granite quarry, black powder, owing to its slow and heaving action, is almost invariably employed. It is also still largely used in many coal mines, especially in the modified form of Bobbinite, which contains much less nitre and sulphur, with more charcoal and in addition starch and paraffin wax, and is much liked as it produces a minimum of small coal. This type of explosive has also the advantage that it does not require a detonator, but is fired by simple ignition.

The cheaper sodium nitrate is frequently used instead of the potassium salt in America, but requires more protection against moisture. The substitution of ammonium nitrate gives a most excellent smokeless propellant, but the hygroscopic character of the powder has prevented it from coming into practical use.

It is interesting to note that small quantities of potassium perchlorate are sometimes found in saltpetre made from the Stassfurt potassium salts, but it is recognised that powder made from such saltpetre is not more dangerous than when free from the perchlorate.

Until a few years ago, no explosive containing potassium chlorate was in practical use. Although many mixtures containing this ingredient had been patented from time to time, they were always too sensitive to explosion, from blows or friction, to permit of their being manufactured and used with reasonable safety. Since the chlorates and perchlorates became cheaper through electrolytic methods of production, renewed and successful efforts have been made to overcome

this sensitiveness, and several excellent chlorate and perchlorate explosives are now in use. The sensitiveness of the chlorate was overcome by the admixture of oil or fatty bodies, which by their physical nature brought about the required degree of safety. Oils or other highly carbonaceous matter, such as vaseline, have also a modifying and restraining influence from their chemical action on the explosive decomposition of such explosives as cordite.

The perchlorates are less sensitive than the chlorates, and ammonium perchlorate yielding only gaseous products of decomposition is a powerful and useful ingredient. When mixed with a suitable amount of combustible matter, although developing great power, it has the disadvantage of producing hydrochloric acid gas, which would be objectionable in mining work. In practice, this is counteracted by replacing part of the ammonium perchlorate by sodium nitrate, which results in converting the irritating hydrochloric acid into wholesome common salt.

Since it is always a disadvantage to have a hygroscopic body in an explosive, it might be thought that it would be better to use potassium nitrate instead of the sodium salt ; but quite apart from the question of cost, it is inexpedient to use potassium nitrate with ammonium perchlorate, because these two salts soon begin to react on each other, and ammonium nitrate is formed which is much more hygroscopic than sodium nitrate.

Cheddite and blastine are the names of the best explosives of the chlorate and perchlorate classes.

In the ammonium nitrate class the variety of composition is very great, but fundamentally they consist of one or more aromatic nitrocompounds and ammonium nitrate.

Finely divided aluminium is also used in some ammonium nitrate mixtures, such as ammonal, and, on account of its great

heat of combustion, the gases of explosion exert an enhanced pressure, whilst a disruptive effect, comparable to that of the strong nitroglycerine explosives, is produced.

A mixture of ammonium nitrate and aluminium is also a powerful explosive.

Coming now to the nitroglycerine explosives, the strongest of all explosives in use is blasting gelatine. As employed, it is in the form of a stiff jelly and, as water does not affect it, it can be used without any protection under water.

The other varieties of nitroglycerine blasting explosives consist fundamentally of a thin jelly composed of nitroglycerine thickened with from 3—6 per cent. of collodion cotton, and worked up into a stiff plastic mass with a suitable amount of potassium nitrate and wood meal. These gelatinous explosives, although not so unaffected by water as blasting gelatine, are nevertheless sufficiently water resisting to be employed in the wettest of boreholes, without any special protective covering. Their plasticity also enables them to be pressed into the borehole so as to fill completely the portion occupied and thus to be able to exercise the maximum rending power.

The nitroglycerine explosives have the drawback that they freeze at 8° C. and must be thawed before use. This can be safely done if the proper hot water jacketed pans are used and the explicit instructions issued by the makers are followed. Unfortunately, miners and quarrymen are sometimes reckless and impatient with the safe way of thawing, and try such rough-and-ready means as placing the cartridges in a kitchen oven or holding them on a shovel over a fire, and many lives have been sacrificed through this rashness.

The explosives just described are typical of those in general use for blasting purposes, but there are a very large number of

variants of these types which specially commend themselves to different manufacturers and their customers.

Now as to detonators—nearly all blasting explosives, except black powder are fired by means of a detonator. Fulminate of mercury is the most widely employed constituent of the detonator charge, sometimes it is used alone, but more usually with an admixture of 20 per cent. of potassium chlorate.

Trinitrotoluene, picric acid, and tetranitromethylaniline, each with a small quantity of fulminate as primer, have also been used for charging detonators.

More recently lead azide prepared from the sodium salt of hydrazoic acid N_3H, by means of a lead salt, has also been used, as it has a greater power of initiating detonation, so that less azide is required to detonate an organic explosive than would be required of fulminate. Its manufacture, however, is more delicate than fulminate, and the formation of large crystals must be avoided, as they have the unpleasant property of sometimes exploding spontaneously.

Another new explosive body which appears likely to play an important part as a charge for detonators is tetranitro-aniline, manufactured by nitrating metanitroaniline. It combines an exceptional explosive power with aromatic stability and has a high density.

It can be easily detonated, even when highly compressed, and has such a high percentage of oxygen that it can be detonated without residue or smoke.

Before an explosive can be legally manufactured or used in this country, it has to undergo an examination by the chemical advisers of the Explosives Department of the Home Office. If the tests are passed satisfactorily, it then becomes an " authorised " explosive, and can be dealt with accordingly.

Explosives for general use should be sufficiently insensitive to blows or friction to be safe with reasonable handling; and the ingredients should be so well purified and especially freed from acid that there is no danger of slow decomposition setting in, which in time might become dangerous.

Black gunpowder, ammonium nitrate, and perchlorate and chlorate mixtures give practically no trouble in this last respect, but explosives containing nitroglycerine and nitro-cellulose have to be carefully tested.

The "Heat Test" is the official and quickest means of ascertaining whether any decomposition is going on in an explosive, or whether it can be considered safe. The test consists in heating, at a prescribed temperature, a certain quantity of the explosive in a test tube closed by a cork through which passes a glass rod carrying at its lower end a strip of starch iodide paper moistened with glycerine. After some minutes, a brown line appears at the junction of the moist and dry part of the paper. The number of minutes taken to produce this brown line constitutes the test, and is the measure of condition of the explosive. A certain number of minutes are prescribed by the Government for the different classes of explosives, and unless an explosive stands the test of its class without showing discoloration of the paper before he specified number of minutes have elapsed, it is considered unsafe and may be rejected or its use prohibited.

Naturally a test which, from its official nature, has such power for weal or woe to the manufacturer has been the subject of much controversy, and for several years a committee composed of Government officials and representatives of the explosive industry has been engaged in experimenting with and studying this test with the object of solving some of its anomalies.*

The indications of the heat test are undoubtedly very

* The report of this committee was issued in April, 1914.

valuable, but must not be strained. It affords a rapid means of checking the purification of nitroglycerine and nitro-cellulose, and while there may be difference of opinion as to the interpretation of a " long " heat test, all are agreed that a very " short " heat test indicates imperfectly purified material which will inevitably cause trouble, and be dangerous, unless it be further purified.

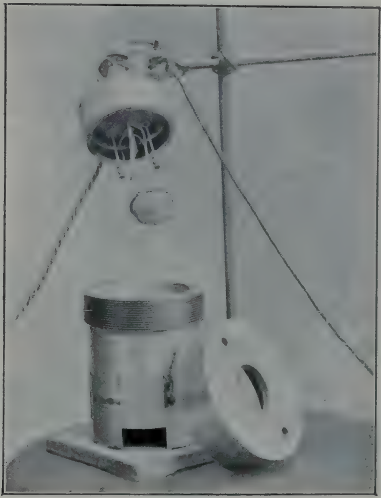
All these nitrated esters undergo more or less rapid decomposition when heated. Another test consists in heating the material in a long narrow test tube to 135° C. and observing the lapse of time until the first appearance of faint brown fumes. It is advisable to place the bath and tubes behind a thick sheet of plate glass, as occasionally a fairly violent explosion takes place.

Dr. Will elaborated a test for measuring the amount of NO given off from nitrocellulose when heated under uniform conditions. He found that from thoroughly purified samples a constant quantity of gas is given off in equal intervals of time ; a normal decomposition curve can thus be prepared for the different nitrocelluloses. Any serious departure from the normal curve shows the sample under examination to be more or less bad, according to the amount of divergence.

The late Dr. Dupré devised a test on similar lines. The apparatus is on the table. The nitrocellulose is heated to 135° C., and instead of chasing away the evolved products of decomposition as quickly as they are formed and then measuring them, as in the Will test, the products are delivered into the vacuous end of a siphon barometer tube. After fifteen minutes, the rise of the alcohol over the mercury in the open end of the barometer tube is measured. By turning the taps and rapidly evacuating the barometer tube again, the observations are repeated at quarter-hour intervals, and in this way the rate of evolution of the gas can be traced, and any departure from the normal detected.

Dr. Robertson has studied the decomposition of nitroglycerine on the same lines as Will tested nitrocellulose but, on account of the volatile nature of nitroglycerine, special precautions had to be taken, and he devised a very ingenious apparatus of which I can show you the principal distinctive part.

Here is a Berthelot calorimetric bomb in which I have made many hundreds of determinations, firing charges up



BERTHELOT BOMB.

to 6 grams. I regret I cannot show you another bomb in which 100 grams of a high explosive can be detonated; as it weighs about 2 cwt., its manipulation involves a fair amount of muscular chemistry.

The volume of gas after an explosion can be measured by admitting it into an accurately calibrated vessel of approximately the volume of the gases generated, connected with a mercury gauge, and noting the plus or minus pressure. Also

through the kindness of Dr. Robertson, I can show you a photograph of his apparatus designed for this purpose.

Here is another bomb fitted with a crusher gauge for measuring the pressure by means of a piston acting on a soft copper cylinder : the diminution in length or compression of the copper cylinder is a measure of the pressure.

It was by means of a similar instrument that Vieille determined the rate of combustion of powder. A fine steel pen was attached to the piston and pressed against a uniformly revolving drum. Before the explosion the pen traced a circle round the drum. During the explosion a more or less slanting line was formed, corresponding with the rapidity of combustion, which developed into the straight encircling line when the piston came to rest. In this way he carefully studied the rate of combustion of his various powders, and finally worked out the French military smokeless powder.

You have no doubt observed that the name powder is entirely a misnomer, as applied to modern propellant explosives, as they are made in all sorts of forms—cords, tubes, rods, cubes, etc., such as are here exhibited ; still they are all called powders, and the word has been retained in a similar way in all languages.

In blasting operations, gunpowder and detonators are either fired by a time fuse or electrically. The time fuse consists of a thin but continuous core of black powder covered by a case of twine and tape and varnish. It is made to burn at a known uniform rate, generally 2 feet per minute, in order that a sufficient length can be used to allow the shot-firer, after lighting the fuse, to reach shelter before the explosion takes place.

The instantaneous fuse, which burns at the rate of 100—300 feet per second, affords a means of firing many charges simultaneously.

Occasionally it happens that a coil is defective, generally through discontinuity in the powder core. C. Napier Hake, late Chief Inspector of Explosives for Victoria, ingeniously employed X-ray photography to examine suspected coils and, in this way, was able to recognise those which were defective.

Through the kindness of Messrs. Bickford, Smith & Co., I can show you various samples. One of the most interesting recent productions is the "detonating fuse," a soft metal tube filled with trinitrotoluene which detonates with greater velocity than most explosives. When placed alongside the cartridges in a deep borehole, it is considered to give an enhanced blasting effect by causing the whole charge to go off more simultaneously than when the column of explosive is fired at one end by a detonator in the usual way.

This detonating fuse has been employed in an ingenious way by Dautriche for measuring the velocity of detonation of explosives. This method depends upon the use of a special detonating fuse having a uniform velocity of 6,000 metres per second. A suitable length of fuse, according to the length of the column of explosive to be tested, is taken for the test, and the exact middle of the fuse is determined by measurement, and marked. A fulminate cap containing a charge of 1 gram is slipped over each end of the fuse and pinched securely. The fuse is then laid upon a piece of 32 pound sheet lead ($1\frac{1}{2}$ inches $\times$ 15 inches $\times$ $\frac{1}{2}$ inch) or ($38 \times 380 \times 13$ mm.), so that the centre of the fuse is about in the centre of the strip of lead, and the point coinciding with the middle point M of the fuse is marked plainly on the sheet lead.

The fuse passes along the entire length of the sheet of lead and its ends are bent round so that they nearly meet. The two ends of the fuse covered with the detonating caps are inserted a short distance, at two points, into the column of explosive, the detonation velocity of which is to be tested, and the

distance between these points is accurately measured. This may be called (A). A fulminate cap with the fuse or electric connections is placed in one end of the cartridge of explosive. When this cap is detonated, the explosion wave proceeds through the detonating fuse in both directions and meets at a point (T) where a sharp line is formed by the effects of the detonation itself, and the lead is sometimes broken through at this point.

The distance from (M) to (T) is accurately measured and designated as (b). If the two ends of the fuse are detonated simultaneously, (M) and (T) fall together, that is, the detonation proceeds at the same rate through the two halves of the fuse and meets at the middle, but when a certain length of an explosive is placed in the circuit, we have on one side half the length of the fuse plus a certain measured length of explosive.

Supposing, therefore, that—

X = Velocity of detonation of the explosive tested.
V = Known velocity of the fuse (6,000 metres per second).
A = Distance between two ends of fuse, or length of explosive tested.
b = Distance between M and T.

Then—

$$X = \frac{VA}{2b} \text{ or } \frac{6000A}{2b}.$$

As to the accuracy of the test, it was found that by using the fuse alone (M) and (T) always coincided to within $\frac{1}{8}$ inch (3 mm.). It is easily seen that errors in measurement will be diminished by increase in the length of the explosive tested, and it can be calculated with velocities of 4,000 to 6,000 metres per second, using 15 inches (38 cm.) of powder, that an error of $\frac{1}{4}$ of an inch (6 mm.) in measurement of the distance (M) to (T), which is a very large one under the conditions, introduces an error in the determination of the velocity of about 3 per

cent., an amount which is well within the limit of error of the more elaborate Bichel method.

In judging the relative strength and suitability of explosives for particular work, various tests are employed from which with experience a fairly correct idea may be formed.

The Trauzl test is very useful. A lead block 200 mm. in diameter and 200 mm. high with a central hole 125 mm. deep and 25 mm. diameter deep is employed; 10 grams of the explosive with a detonator is placed in the hole which is then filled with sand and fired electrically, a large cavity is formed and its size measured by pouring in water from a graduated cylinder. The volume thus found is a measure of the force of the explosive. The velocity of detonation of the explosive has a great deal to do with the size of the cavity produced, and the test must not be accepted as a true expression of the power, but it is exceedingly useful when comparing explosives of the same order.

The shattering or brisance test is carried out by firing 100 grams of the explosive placed on the top of two cylinders of lead protected by steel discs and noting the compression and deformation of the lead cylinder.

Detonators are often tested in a somewhat similar manner, and I can show you the experiments of firing one in a minature Trauzl block and on a sheet of lead.

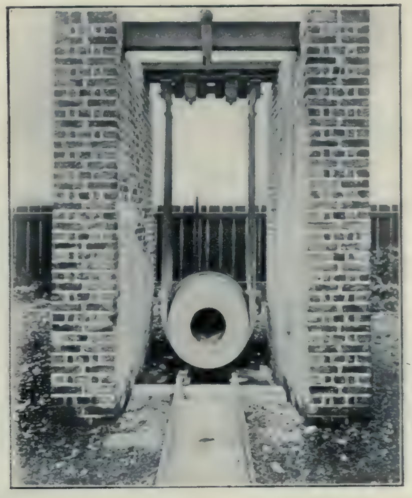
The falling weight test gives a measure of the sensitiveness to shock. A weight of one to two kilograms is usually employed and the lowest height noted from which, when dropped on to a small portion of the explosive, it causes explosion.

The ballistic pendulum is also used as a measure of power. A charge is fired against the heavy bulb of the pendulum, and the distance of the swing noted.

All these tests are helpful and illuminative, but the most decisive of all is to find out how much progress can be made,

say, in driving a heading under similar conditions, expressed in terms of the explosives used and time occupied.

In the next lecture it is proposed to deal more especially



Ballistic Pendulum, Home Office Testing Station.

with the manufacturing side of the subject and the restrictions under which the construction of the works and the operations have necessarily to be carried on.

A number of lantern slides kindly lent by Sir Frederic Nathan and Messrs. Bickford, Smith & Co., were shown, illustrating the effects of accidental and intentional explosions.

Lecture II.

In the previous lecture, we were principally engaged in considering the character of explosive phenomena and the general qualities of the explosives most usually employed, as well as some of the methods of testing their qualities. To-night, more attention will be given to the manufacturing processes involved and to the special conditions under which the manufacture has to be carried on, owing to the restrictions imposed by the Home Office.

With the object of preventing accidents as far as possible, and minimising the loss of life should an explosion occur, a number of rules and regulations have been drawn up by the Explosives Department of the Home Office which have to be followed in the construction and working of explosive factories

These rules and regulations have been evolved by careful consideration and as the result of experience. Whilst, in some instances, they may be felt to be needlessly irksome, still they have undoubtedly helped in the saving of life and property, and the manufacturers in their own interests, as a rule, loyally carry them out. In any case, the " Law " must be obeyed; otherwise trouble follows.

In explosive works, there is a " non-danger " area, in which the boilers and engines necessary for the heating and motive power, as well as repairing shops and departments for manufactures such as acid making are carried on, free from any exceptional restrictions. The designing of this part of the works can be carried out in the most economical manner which the character of the site and the requirements permit, and the

different buildings may be placed as close to one another as may be desired.

In the "danger-area," however, where the manufacture of the explosives proper is carried out, the case is quite different. The object of the restrictions is to allow only limited quantities of explosive material and a limited number of workpeople in one building at a time and, further, to place the different

"MOUNDED" HOUSE, COTTON POWDER WORKS.

buildings at such distances from each other, or surround them by protecting earth mounds, that in the event of an explosion the effect is localised as much as possible and the explosives in the adjacent buildings are not "set-off."

Tables have been drawn up showing the distances which must be maintained between the different buildings according to the amount of explosive which is licensed to be in each building. If there is no protecting mound the distance is about double that which is allowed when the building is

mounded. As the construction of the mounds is expensive, it is sometimes more advantageous where land is available to place the buildings more widely apart and thus avoid the cost of mounds; on the other hand, where the buildings have to be heated, it is important to have them as close together as the law permits, in which case they will be well mounded. Hitherto, it has been the practice to construct the danger buildings

Buildings and Pipe Connections, Cotton Powder Works.

of light material, generally of wood, the idea being to prevent the projection of heavy pieces of masonry or bricks which might cause serious damage or explosion in neighbouring buildings. The advisability of this method of construction has been questioned in recent years, and the late Oscar Guttmann proposed that the buildings should be made strong enough to resist damage by falling *débris*, so to speak, bomb proof. By constructing them of sand concrete, it was hoped

that, should an explosion occur in such a building, the walls and roof composed of this sand concrete would be pulverised and not projected in lumps which would be dangerous to other buildings. Steps are being taken by the Government and some private firms to test practically this method of construction, and it will be interesting to see if it offers greater security than the system at present adopted.

Special precautions are taken to prevent the accumulation of dusty explosive matter, and scrupulous cleanliness is enforced. No naked iron or steel is allowed where the more explosive materials are treated ; the workers have to wear shoes containing no iron or steel nails ; and, in order to prevent the introduction of grit from the outside, those entering the building temporarily have to slip on large shoes which are kept at each building specially for this purpose. Everyone on entering an explosive works has to give up any matches he may have in his possession ; the workpeople have to wear special outer clothing without pockets ; and women have to fix their hair without pins which might possibly fall in among the explosives with which they are working.

The lighting of the buildings is nearly always electrical, and where motive power is required, it is usually supplied by electric motors placed outside the building.

In some of the older gunpowder works, however, water power is employed for driving the mills. In each house, notices are affixed stating the number of workers and the quantity of explosive material allowed as well as the nature of the operation to be carried on.

It is not permissible to use a house for a different operation from that for which it is licensed, without special authorisation. Serious penalties follow the breach of the terms of the licence under which the factory is allowed to work, and surprise visits from the Inspectors of Explosives help to maintain a good state of discipline.

In the manufacture of black powder, the three ingredients—nitre, charcoal, and sulphur—after preliminary mixing are incorporated under heavy edge runners. The milling is continued for several hours, water being added from time to time in sufficient quantity to keep down dust and, finally, the explosive is removed from the bed of the mill in the form of "mill cake." This is afterwards broken up and compressed between copper sheets in a strong hydraulic press. The resulting cakes are then granulated by being passed between a series of toothed rollers under which are fixed screens of different sizes, which separate the grains into the desired sizes. The grains are then glazed by treatment with a small quantity of graphite in a revolving barrel. After removal of the dust, the explosive is heated in a stove to drive off the excess of moisture and is then ready for use.

The late Henry de Mosenthal, who was an expert microscopist, told me that when examining the minutest particle of high-class powders under the microscope, he had invariably detected the three ingredients. This shows what an efficient mixing had been attained.

Formerly, when black powder was the only military propellant, great care had to be taken in the selection of the wood and in burning it into charcoal, as the composition and condition of the charcoal had an important bearing on the final qualities of the powder. This is of less moment for blasting powders.

The manufacture of guncotton and the other forms of nitrocellulose is carried out in the first stages in the non-danger part of the factory. The raw material is cotton waste which is specially prepared for the explosive manufacturer. First, it is hand picked, in order to remove all foreign matter as much as possible, and it is amazing to see how much rubbish in the form of pieces of wire, wood, nails, etc., is thus removed.

Next, it is teased and dried, because cotton ordinarily contains about 10 per cent. of moisture, and this water would needlessly dilute the nitrating acids. The photograph shows a drying plant in use at Waltham Abbey. The older method of nitration, still followed by some factories, consists in dipping charges of 1¼ lb. of the dry cotton waste in a mixture of one part of strong nitric acid 1·5 sp. gr. and three parts of sulphuric acid 1·84 sp. gr. The mass of cotton, after immersion in the acid

Drying Machine, Waltham Abbey.

for a few minutes, is removed to a grating and the excess of acid squeezed out; after which, still soaked with acid, it is placed in an earthenware pot, and after covering with a lid, the pot is stood in water for about twelve hours. By this time, the nitration is complete and the contents of several pots are removed by means of tongs and placed in a centrifugal machine which frees the guncotton from the excess of acid. The nitrocotton is then removed from the centrifugal and

immersed in a tank full of running water until it no longer reddens litmus.

After this preliminary washing, the nitrocotton is boiled in water for many hours, with changes of water. It is still in the fibrous form and is now pulped in a beating engine similar to those used in paper works, where the fibres are reduced to an extremely fine state of division. The water is often changed

ABEL NITRATION PROCESS, DIPPING PANS, WALTHAM ABBEY.

while the pulping process is going on, and the nitrocotton may be sufficiently purified when this operation is completed or it may be necessary to give it another boiling.

Such is the older method of nitration and purification.

Nitrating centrifugals are also advantageously employed. These are specially constructed centrifugal machines which can be filled with the mixed acids, and a much larger weight of cotton, generally about 17 lb., is immersed and allowed to remain in the acids for about an hour, when the nitration is

complete, the excess of acids is run off and the remainder extracted by setting the machine in motion. This method has the advantage that the nitration is carried on much more quickly; less space and labour are required, and the workmen are less exposed to the acid fumes. On the other hand, the initial cost is greater and should a charge "fume" off, as occasionally happens, a greater quantity of guncotton

ABEL NITRATION PROCESS, GENERAL VIEW, WALTHAM ABBEY.

is lost than in the case of one of the much smaller pots fuming.

The most interesting development of the nitration process is the method devised by J. and W. Thomson, of the Royal Gunpowder Factory, Waltham Abbey. The plant, which is simple and inexpensive, consists of shallow earthenware circular pans grouped together in sets of four; they are provided with perforated false bottoms, and the opening in

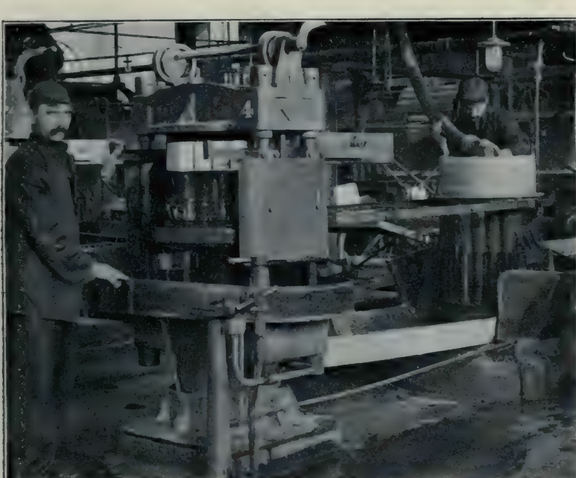
the bottom of each pan is connected to pipes supplying the nitrating acid, and to pipes for the removal of the spent acid. These pans are filled to a suitable depth with the nitrating acids and a charge of 20 lb. of dry cotton is gradually introduced. Aluminium hoods connected with an exhaust fan take off the fumes from the acids. When all the cotton is immersed, perforated earthenware plates are laid on top of

Displacement Process, Waltham Abbey.

the cotton to keep it under the acid, and then a thin film of water is cautiously run over the surface of the acid. This film prevents the fumes from the acids escaping and the aluminium hoods can be removed. After standing two and a half hours the nitration is complete; the spent acid discharge cocks are opened cautiously, and a corresponding quantity of cold water allowed to flow on to the surface. In this way, it is possible to displace the spent acids much more completely than by the older methods. The water is then allowed to

drain away and the guncotton is ready for the subsequent processes of purification.

The purified and pulped nitrocotton is run into a moulding machine where it is lightly compressed, to remove the greater part of the water, and made into small cylinders which can be easily handled ; or, if required for torpedo charges, etc., it is highly compressed into dense hard blocks. Up to this point, the nitrocotton has been treated as non-explosive, but in order



Moulding Machine, Waltham Abbey.

to dry it, it is removed to one of the stoves or drying houses in the danger area. Dry guncotton is one of the most dangerous explosives, as when dry and warm it is very liable to explosion by friction and the greatest care has to be exercised in handling it in the drying house.

The displacement process is used chiefly for making the highly nitrated guncotton, but it seems possible that it may also be used for the production of lower nitrocottons.

All nitrocelluloses are manufactured substantially in the manner above described.

The acids are generally stored in iron vessels, such as old boilers, and means are provided whereby the desired quantities of sulphuric and nitric acid can be accurately measured and run into the mixed acid container. The composition of the nitrating acid must be carefully controlled by analysis.

Beating Engines and Poacher, Waltham Abbey.

The spent acid can be revivified by the addition of suitable quantities of nitric and sulphuric acid, the latter often in the form of "Oleum," when the nitrating acid must contain little water. Such revivified acid can be used many times, but the bulk gradually increases from the formation of water in the reaction between the nitric acid and the cellulose, and also the acid gradually becomes charged with impurities which make its action less effective; so that after a certain time,

according to the practice in the works, it is either denitrated—by passing it down towers filled with siliceous material up which a current of steam passes carrying off the nitric acid and leaving the diluted sulphuric acid behind—or else the spent acid may be used directly for decomposing sodium nitrate in the production of nitric acid. The manufacture of nitrocellulose is one of the most troublesome processes which the explosive chemist has to carry out.

As many of you know, the composition of the acid mixture is of the greatest importance and largely determines the character of the product. The ratio between the nitric and sulphuric acids and the water must be accurately adjusted.

The following general statement may help to explain the principles underlying the nitration process :—

With the same ratio of H_2SO_4 to HNO_3 the amount of the nitrogen in the nitrocellulose decreases as the water is increased in the mixed acids.

Alteration in the ratio of the acids has not much effect with the lower percentages of water, but increase of the sulphuric acid leads to increase of nitrogen when the water is about 14 per cent. and over. It thus becomes possible to produce nitrocelluloses with the same amount of nitrogen from acid mixtures containing different quantities of water.

The solubility in ether-alcohol also increases as the water is increased in a nitrating mixture of the same ratio of acids, while with the same amount of water the solubility decreases as the sulphuric acid increases.

The products of nitration are not formed in clear cut stages of mono-, di-, tri-, etc., nitrate, rather it may be said that the different stages merge so imperceptibly into one another that, within limits, any percentage of nitrogen can be produced, by selecting a nitrating bath of suitable composition.

The composition of the nitrating bath in the displacement process may be taken as : sulphuric acid, 71 ; nitric acid, 21 ;

water, 8. This yields a guncotton containing about 13 per cent. of N, and nearly insoluble in ether-alcohol, whereas a bath containing sulphuric acid, 56·7 per cent.; nitric acid, 28·3 per cent.; water, 15 per cent., would give a nitrocellulose containing about 12 per cent. of N, and entirely soluble in ether-alcohol. The explosiveness of the nitrocellulose increases with the nitrogen in it.

It must also be remembered that the cotton is by no means a definite chemical body, and its physical state plays an important part. Samples of different cottons, under the same conditions in a bath of the same composition, while yielding nitrocelluloses containing practically the same percentage of nitrogen, may vary in solubility in ether-alcohol from 25 per cent. to 70 per cent. In some cases the viscosity of the ether-alcohol solution is of importance; this again is affected by the nature of the cotton and, with the same nitrating bath, different cottons may show great differences in viscosity.

In the early days, a high degree of nitration, say 12·8 per cent. of nitrogen and upwards, was generally associated with great insolubility in ether-alcohol, and the solubility increased as the nitrogen content diminished. Now, however, as the effects and influences of the three components of the nitrating bath HNO_3, H_2SO_4, and H_2O are better understood, it is possible to produce nitrocellulose with a very high percentage of nitrogen, and at the same time complete solubility in ether-alcohol.

Some years ago, during an important legal case, the "solubility" and "insolubility" of nitrocellulose in ether-alcohol became of great moment. Solubility in ether-alcohol being held by one side to connote a comparatively low percentage of nitrogen, it was deemed desirable by the other side to try to show that guncotton, which was generally regarded as practically insoluble in ether-alcohol, could nevertheless be considered "soluble." In this connection, I succeeded in dissolving

highly nitrated "insoluble" guncotton in ether-alcohol, by treating it in contact with the liquid at a very low temperature; the tube containing the guncotton and ether-alcohol was embedded in solid carbonic acid. This is a sample of the horn-like mass which remained after the ether-alcohol had been driven off, and I believe this is the first specimen which was ever produced in that way. It is remarkable that a solvent action which did not occur at normal temperature should have been brought about at a very low temperature.

In the preparation of nitrocellulose suitable for gelatinising nitroglycerine, much experience is required. The percentages of nitrogen or the properties of ether-alcohol solution are not a sufficient guide; the determining test is an actual trial of gelatinisation of nitroglycerine. It is essential not only that the nitrocellulose should produce a sufficiently stiff jelly, but one which will preserve its jelly-like character under all sorts of conditions of storage, and not exude nitroglycerine. A large quantity of gelatinous explosive is exported from this country to Australia, and the passage through the tropics is a severe test of the excellence of the manufacture. The difficulty is to produce a jelly which will not exude nitroglycerine. However, many of the manufacturers now understand better how to produce a nitrocellulose which will retain the nitroglycerine under the trying conditions of hot storage in the hold of a ship going through the tropics. The gelatinising power of nitrocellulose seems to depend more on the physical character of the cotton than on the composition of the nitrating bath and, broadly speaking, it may be said that the less the cotton fibre has been subjected to mechanical or chemical treatment before nitration the better its gelatinising power.

Much good work has been published on the nitration of cellulose and much special knowledge is locked up in the laboratories of many of the larger works for private consumption.

Turning now to the production of nitroglycerine: this manufacture is much simpler than that of nitrocellulose; at the same time, it is much more dangerous. As already stated, the manufacture of guncotton, up to the drying process, is free from danger. Nitroglycerine, however, being a liquid insoluble or nearly so in the nitrating acids and in water, always retains its explosive properties and has to be treated with great care.

When it was first produced for industrial purposes, small quantities of glycerine, less than a pound at a time, were nitrated in earthenware pots; now, a charge of 1,400 lbs. of glycerine is nitrated at one operation, in one apparatus, and the whole process is so well under control that it rarely happens that an explosion occurs during nitration.

The plant which is at present most employed is known as the nitrator-separator. It was developed at Waltham Abbey by Sir Frederic Nathan and W. Rintoul, and is a great advance on the former methods.

The nitrator-separator is a cylindrical leaden vessel with a coned top; inside are placed leaden coils, through which cooling water circulates, and pipes, through which compressed air is blown to mix the contents. The glycerine is introduced in the form of a fine spray under the acid by means of a special injector worked also by compressed air.

Long thermometers, passing through the top of the nitrator-separator enable the temperature to be watched, and it is the business of the man in charge of the operation to see that the temperature does not rise beyond a certain point, generally 28° C. By reducing the flow of the glycerine and by increasing the agitation with the air, any undue tendency to rise can usually be checked. Should, however, the temperature continue to rise and pass the danger mark, then a large cock in the bottom of the nitrator is opened and the contents are rapidly discharged into a large tank containing water outside the building,

where the charge is "drowned" and thereby the danger avoided of serious decomposition and probable explosion.

When everything goes right, the nitration of the charge is usually completed in about one hour, the agitation with the air is discontinued and the separation of the nitroglycerine from the acids takes place—being lighter it comes to the top. A pipe, in which a glass window is fitted, leads from the top of the nitrator-separator to a pre-washing tank; by allowing

NITRATOR-SEPARATORS.

waste acid from a previous operation to enter at the bottom, the nitroglycerine is forced over into the washing tank; and the flow of acid is stopped whenever all the nitroglycerine has passed into the washing tank which can be observed through the window. Formerly the mixture of acids and nitroglycerine was allowed to flow into a separator, another leaden vessel, in which the separation took place, the nitroglycerine being skimmed off with a dish by hand; but

the new nitrator-separator is much more effective and also safer. By a clever arrangement of large indiarubber pipes, the nitroglycerine can be transferred from one vessel to another without having to pass through stop-cocks, which were always a source of trouble and danger. Washing in the pre-wash tank with several changes of water soon removes the bulk of the acid adhering to the nitroglycerine, and a wash with a dilute solution of sodium carbonate finishes the pre-washing; the nitroglycerine is allowed to flow into the final washing tank where it gets several washes with sodium carbonate solution and finally water, after which it is filtered through sponges or salt in order to remove traces of water or flocculent matter. In most factories, the washing is carried on in a separate building. This necessitates conveying the nitroglycerine along a leaden gutter which has to be protected from the weather and must also be easily accessible. Through the kindness of Messrs. Curtis's and Harvey, I had the opportunity of inspecting a nitrator-separator plant which they have recently installed wherein 1,400 lbs. of glycerine are nitrated in one operation. The plant is so arranged that all the operations of separating, washing, filtering, and weighing, or rather measuring, the nitroglycerine and running it into the rubber bags, or boxes, containing guncotton or collodion cotton respectively, are accomplished in the one building. This arrangement has the great advantage of doing away with the gutters for conveying the nitroglycerine from one house to the other.

Formerly the composition of the nitrating acids was 3 parts of the strongest nitric and 5 parts of the sulphuric acid 1·84 sp. gr., and generally one part by weight of glycerine was added to 8 parts by weight of the mixed acid. The practical yield of the nitroglycerine was about 214 per 100 of glycerine instead of the theoretical 246·7. It is now the practice to use mixed acids containing much less water, by the employment

of a suitable quantity of Nordhausen sulphuric acid. This also permits of a less quantity of the mixed acid being used and, owing to the change in the composition of the acid mixture and the use of the nitrator-separator, the yield of nitroglycerine has been increased to over 230 per cent. In many works it is customary to have refrigerating plant so that the cooling water can be reduced in temperature when necessary, and thus the operations can be carried on under uniform conditions in summer or winter. The purity of the acids and their freedom from matter in suspension, as well as the purity of the glycerine, have a great effect on the rapidity and completeness with which the nitroglycerine separates from the acids.

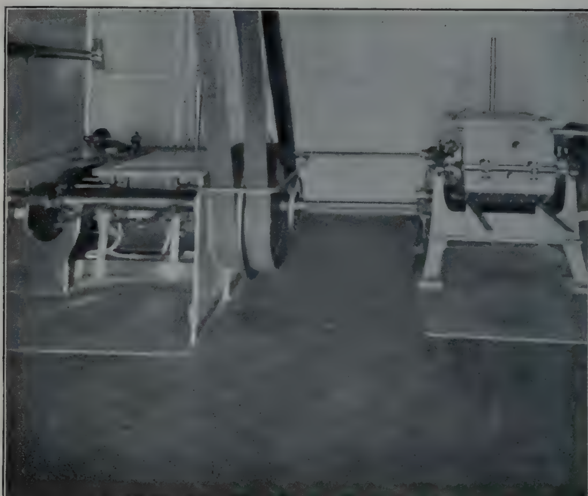
A certain quantity of nitroglycerine is carried away mechanically by the wash waters and, to recover it as far as possible, the waste waters are run through labyrinths fitted with baffle plates in which much of the nitroglycerine carried away is deposited. The waste waters are finally run into a pond, in which a cartridge of explosive is fired, once a week, to explode any nitroglycerine which may have escaped settlement in the labyrinth and so prevent any danger through its accumulation.

When blasting explosives are to be made, the nitroglycerine is run into boxes containing the proper quantity of collodion cotton. For blasting gelatine, which contains about 7—8 per cent. of collodion cotton and 92—93 per cent. of nitroglycerine, the ingredients are well mixed by hand and often allowed to stand over night before being placed in steam jacketed pans provided with mechanical mixing arrangements, where they are heated to 50° C. and thoroughly incorporated until the required consistency has been attained.

In the case of gelignite or gelatine dynamite, potassium nitrate and wood meal are added to the mixture of nitroglycerine and collodion cotton, and the charge treated in a similar manner to blasting gelatine. These gelatinous explosives are fed into a sort of sausage machine from which they

emerge in a continuous cylinder of the desired diameter; they are cut up by an arrangement of knives into suitable lengths, wrapped up in parchment paper, and thus constitute the ordinary blasting cartridge.

In the manufacture of cordite, the nitroglycerine is run on to guncotton contained in rubber bags and hand mixed; this is known as cordite paste. In this way it is conveyed to the

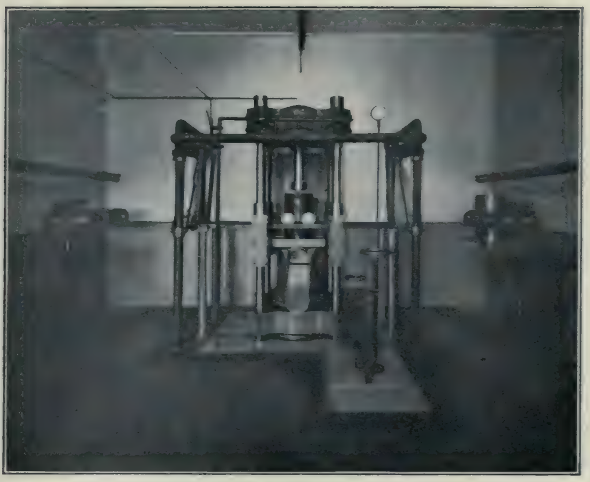


Cordite Mixing Machine.

mixing house, where the contents of the bags are transferred to a large Pfleiderer mixing machine containing the requisite quantity of acetone. After some time mineral jelly is added, and when the charge has been sufficiently gelatinised it is taken to the presses which are worked by a screw, for the smaller sizes, and by hydraulic power for the larger. There it is squirted through dies of the required sizes; in the case of rifle cordite the thin cords are wound on a reel, whilst the thicker varieties are cut into suitable lengths.

The cordite must now be dried in order to drive off the last traces of acetone. In the case of the larger sticks of cordite—MD—containing the smaller quantity of nitroglycerine—30 per cent.—this drying takes about two months. When finished the different sizes are tested in the guns for which they are intended, and the different batches blended so as to give as nearly as possible the velocities and pressures stipulated.

It is interesting to note the accuracy which has been



CORDITE PRESS.

attained in this manufacture. For rifles, for instance, the velocity prescribed is 2,380 foot-seconds, with a *plus* or *minus* of only 40 feet and a pressure of 19·5 tons with a maximum of 20 tons per square inch.; for larger guns it may be 2,500 foot-seconds ± 15 foot-seconds, and the pressure must not exceed 19 tons per square inch.

The ingredient "mineral jelly" in the cordite plays an important part both in moderating the force of the explosion by lowering the heat of combustion and increasing the volume

of the gases and also by adding to the stability of the explosive; for it has been found that the decomposition products of cordite, resulting from long storage at high temperatures, are absorbed by the mineral jelly, and further decomposition is at any rate retarded.

Lest we become too proud of our present day attainments, it may be well to recall that in "*Pseudodoxia or Vulgar Errors*," written in 1646, Sir Thomas Browne shows that the influence of fatty bodies on explosives was then appreciated. Speaking of statements about powder which could be discharged without report, he says: "To destroy the report, it is reasonably attempted, but in two ways; and that is either by quite leaving out or else by silencing the saltpetre. How to abate the vigour thereof or silence its bombulation, a way is promised by Porta, and that not only in general terms by some fat bodies, but in particular by borax and butter mixed in due proportions; which sayeth he will go off as scarce to be heard by the discharger; and indeed plentifully mixed it will almost take off the report, and also the force of the charge."

The British Service explosives have to undergo great extremes of temperature in the tropical and Arctic conditions under which they have to be stored in the different parts of the empire. All powders made of nitrocellulose or of nitrocellulose and nitroglycerine very slowly decompose, especially when exposed to great heat, such as a magazine in the tropics.

As the result of much investigation, a quantitative test based on the rate of decomposition of cordite at a temperature of 80° C., approximately the worst that occurs under service conditions, was devised and is known as "the silvered vessel test."

The cordite is ground in a coffee mill and placed in the vacuum jacketed vessel; a thermometer passing through a cork is fixed in the cordite; the apparatus is heated in a bath and maintained at a temperature of 80° C., and the number

of hours noted until the thermometer in the cordite indicates 82° C. Just before the temperature begins to rise brownish fumes are seen in the side tube.

The number of hours which the cordite has stood before showing these signs of decomposition gives a measure of the stability of the samples, and it is possible to calculate the hours into years which the cordite may safely stand at specified temperatures. In this way, each batch of ammunition can be provided with a certificate of character, and, when the periodical examinations show a lapse from the standard required, it can be withdrawn from service and destroyed or otherwise dealt with.

For sporting purposes cordite or any military powder can be used for rifle shooting ; but quite other conditions have to be fulfilled for shot-guns, and the powders have to be modified accordingly. A great many shot-gun powders are on the market, some consisting of nitroglycerine and nitrocellulose, others of nitrocellulose alone, and others again of nitro-cellulose and potassium or other nitrates, often with small quantities of other ingredients. These powders have to be much quicker in their action than rifle powder, for although the weight of the shot is much greater than that of the rifle bullet, the shot is more easily driven out of the gun than the bullet ; consequently, a quicker and stronger initial impulse is required in the shot-gun. This effect is attained largely by the size of the grain or by treating the grain powder so that the grains are swelled and burn with sufficient rapidity.

As mentioned in the former lecture, there are a large number of explosives on the market which are composed of non-explosive ingredients, or ingredients which at any rate are infinitely safer to manufacture and handle than nitroglycerine and nitrocellulose. In this country, however, there are few relaxations of the rules and regulations which are in force for

the more dangerous explosives. In the early days of these explosives, when prolonged experience as to their behaviour during manufacture, storage and use was lacking, it was quite reasonable that no needless risks should be taken, and the new and unproved ammonium nitrate class, for instance, was treated in the same way as the nitroglycerine explosives ; but should a new factory for an ammonium nitrate explosive be started now, the manufacture would still be treated under severe restrictions, in spite of more than twenty-five years' immunity from accident from explosion during manufacture or storage. I know perfectly well that the question is difficult and that the anomaly is not to be ascribed to official obstinacy, but all the same it is desirable that explosives which are incontestably much safer should not be penalised by having to be manufactured under the same expensive conditions prescribed for the admittedly dangerous classes. They should be allowed to compete on the market with the advantage of their inherent propeities.

In the manufacture of explosives in which ammonium nitrate is the principal constituent, special precautions have to be taken to dry it in the first instance: and during the subsequent stages of manufacture, to prevent it absorbing moisture. This involves special heating of the houses and careful protection of the material in tightly closing boxes or containers, when it has to be conveyed from one house to another.

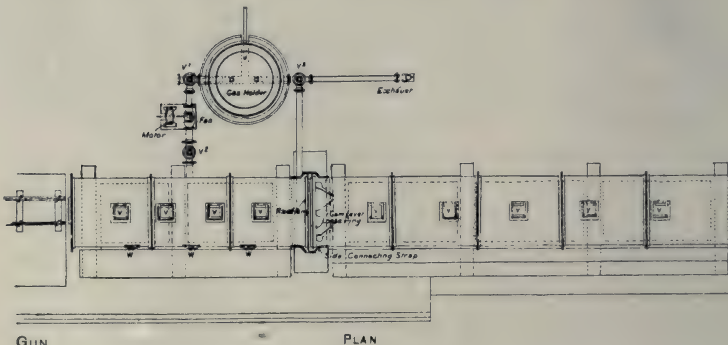
Sometimes the nitrohydrocarbon, such as dinitrobenzene, is first melted in a steam jacketed pan fitted with mechanical stirrers and the dry finely ground ammonium nitrate afterwards added and the ingredients thoroughly mixed ; or, in other cases, the ingredients are mixed in a revolving drum containing brass balls, and the explosive is then filled by machine into paper cartridges, which are subsequently dipped in a bath of melted wax to preserve the contents from the

moisture of the atmosphere. Sometimes the ingredients may be ground together under edge runners as in the case of black powder. In all cases the object is to bring about an intimate mixture of the component parts. The manufacture seems simple and to a certain extent is simple, but it is amazing how many difficulties arise which have gradually to be overcome by experience. It is quite easy to mix suitable ingredients together in a mortar, put them into a cartridge, insert a detonator and get a good explosive effect, but it is quite another matter to make from the same ingredients an explosive which will preserve its full explosive force for a reasonably long time. Sometimes, the cartridge will become hard and fail to detonate, or some other physical change may take place which impairs the effectiveness of the explosive. Of course an undue amount of moisture will impair the explosive, but in practice the ammonium nitrate explosives can be sufficiently protected to remove this as a serious cause of trouble.

When there is cause for complaint in regard to the work done in blasting, the blame is generally put on the explosive; but frequently it is the detonator which is at fault, and the trouble is that there is no positive way of actually proving beforehand whether a cartridge and detonator are good, without exploding them, and, once exploded, they are done for without affording positive evidence that the succeeding cartridges or detonators will be as good or as bad. Again, some explosives can be much more strongly pressed into the borehole without suffering in sensitiveness than others, and consequently complaints may really be due to the miners or quarrymen not properly following the instructions sent out by the makers; and so, especially at the starting of a new works, the lot of the manager or chemist in charge may be "not a happy one." Careful work and observation and experiment, however, will ultimately overcome initial difficulties, and there are on the market many of this class of explosives

which are thoroughly reliable and particularly good for certain work.

With the object of preventing explosions of gas or coal-dust in mines, our Government, in common with many others, has instituted a test which explosives have to pass before they are put on the "permitted" list, and are available for use in fiery or dusty mines. This test has varied in the different countries,



HOME OFFICE TESTING GALLERY, ROTHERHAM.

and a change has been introduced recently, since the transference of the testing station from Woolwich to Rotherham. Much difference of opinion still exists as to the best means of carrying out such a test. The general practice is to fire a charge of the explosive from a "gun" with a 2-inch bore, which may be taken as a borehole, into a cylinder containing an explosive mixture of gas and air, or into the cylinder full of air but with fine coal dust strewed along the cylinder. Formerly the shots were tamped in the English test, but now the cartridge is simply pressed to the bottom of the bore. Shots are then fired electrically until the largest charge is found which can be fired without igniting the mixture. Further shots are then fired until five shots of the same weight have been fired without igniting the mixture. The same procedure is adopted by

firing into air and coal-dust, and the maximum charge determined. The lower of the charges thus determined will be taken as the maximum charge, but for an explosive to have passed the test, the maximum charge must not be less than 8 ounces. This means that the weight of a "permitted" explosive which may be used in one borehole must not exceed the maximum charge determined as above described.

One of the chief factors in determining the ignition is the temperature developed by the gases of explosion. So satisfied were the French authorities that this was the only important point that the theoretical temperature of explosion was calculated, and if it fell below 2,200° C. it was considered safe enough. Owing to lack of data, the temperature cannot be calculated with sufficient accuracy, and other conditions obtain which make a practical test more helpful. Nevertheless the temperature is of great importance and many means are employed of lowering it, such as adding salts which absorb heat on volatilisation.

The rapidity of detonation, the length of the flame and the heat evolved, all influence the readiness with which explosives ignite gas or coal dust; but in this connection knowledge and progress has been chiefly promoted by direct experiment at the various testing stations here and abroad.

Strictly speaking, there is no such thing as a perfectly safe explosive: under certain unfavourable conditions they will all ignite gas or coal dust, but the "permitted test" does enable the various explosives to be sorted into grades of safety, and only those which have shown themselves to be the safest are allowed to be used.

It was considered by the French Firedamp Commission that the presence of combustible gases in the explosion gases added to the danger of igniting the firedamp; on the other hand, it was shown by experiment that the explosive carbonite, which, according to test, was the safest when fired into firedamp,

contained a large proportion of CO and H_2. More recently it has been shown that while the presence of CO and H_2 has no adverse effect on the firedamp, coal dust is more readily ignited when these gases are present.

The filling material for shells has been the subject of much experiment and trial by the different countries. Picric acid, under the various names of melinite, lyddite, shimose powder, etc., has been extensively tried and found wanting. Ammonal, containing ammonium nitrate, with a large percentage of trinitrotoluol and finely divided aluminium, is a very safe and powerful explosive and has been adopted as the charge for shells by the Austrian Government. It has the disadvantage of containing the hygroscopic ammonium nitrate as an ingredient, and must consequently be specially protected against moisture. At present, trinitrotoluol is the body which has commended itself to most of the governments as the best bursting charge for shells, torpedoes and general military blasting work, and has just been adopted by our own Government. It is undoubtedly a stable body and does not act on metals like picric acid. After having been immersed in water for three years its explosive properties were unaltered, and at a factory it has come through the ordeal of a big fire without exploding. It withstands the impact of a rifle bullet and, when in a shell, the impact of piercing an armour plate without exploding. Altogether it seems to be an excellent material for these purposes and is also very safe in handling. It is employed in a state of great purity; the melting point is 80·5° C. and by melting and allowing it to solidify under pressure its density can be increased to 1·6.

Tetranitroaniline, discovered by our friend Dr. Flurscheim, is an equally stable body from the chemical point of view and is a more powerful explosive. It has the somewhat unique

position among explosives of having been discovered in this country.

This is a cartridge composed of 50 per cent. tetranitroaniline, 40 per cent. $Ba(NO_3)_2$, 10 per cent. KNO_3, density over 1·8, and this, as well as similarly prepared cartridges of 65 per cent. ammonium nitrate and 35 per cent. tetranitroaniline, can be easily exploded by a No. 6 detonator. Tetranitroaniline is less sensitive than picric and it would appear to offer many

AEROPLANE WITH BOMB.

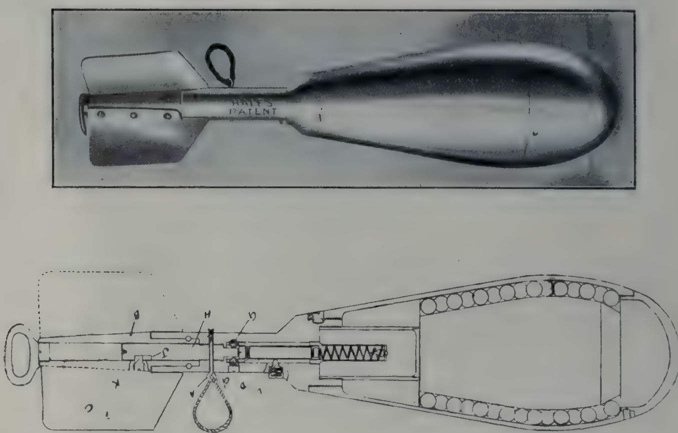
advantages as a filling charge for torpedoes, military blasting and probably for shells and aerial bombs.

In addition to guns in front of one, torpedoes and mines below, we are now threatened with elegant and ingeniously constructed bombs from the skies.

Marten Hale has designed a bomb for dropping from aeroplanes. It is quite safe until a "safety pin" has been

withdrawn and a fall of about 200 feet through the air has caused the propellor to rotate and release the firing mechanism: it is then "alive" and explodes with great violence on striking any object.

His rifle grenade is also another ingenious instrument of destruction and enables a small shell to be fired from an

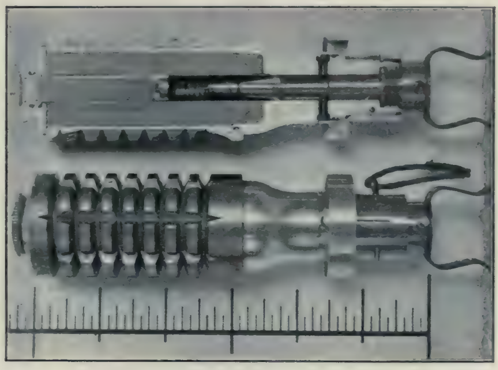


Marten Hale's Bomb.

ordinary rifle to a distance of about 300 yards, when it explodes with deadly effect, and further to aid the work of destruction by night, illuminating grenades can also be fired high in the air from rifles. They burst gently and unfold a small parachute which suspends for a time a brilliantly burning cartridge to illuminate the enemy and enable the rifle grenades to be poured in with greater effect.

Whilst the work connected with the preparation of explosives for military purposes is intensely interesting, the contemplation, even in imagination, of the effects of these means of destruction is truly appalling.

There remains, however, a novel application of explosives, which is in pleasing contrast to the foregoing and comes, like Beethoven's Pastoral Symphony, suggesting the happy feeling of being in the country. No doubt you have heard of the use of explosives in blowing up stumps of trees and clearing land of boulders. In addition, experience in America, South Africa and Australia, has shown that the fruit grower has a real friend in explosives, and it seems to me that, in this country also, we must wake up to this beneficent aspect of explosives



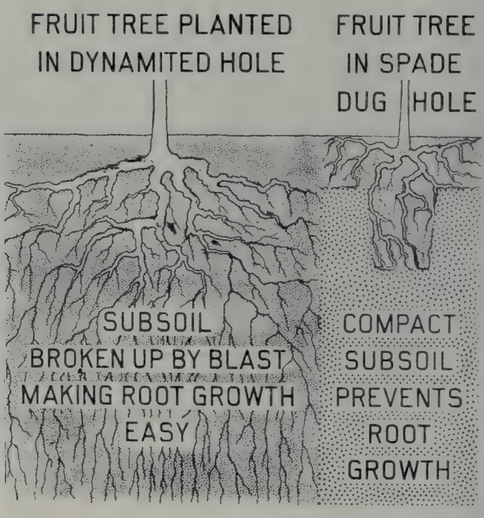
MARTEN HALE'S GRENADE.

and the means they offer of attaining results otherwise impossible.

The particular work to which I wish to call attention is the use of explosives for planting and renovating or rejuvenating orchards. Much has been done in this connection in America, and with such successful results that we cannot afford to neglect this means of improving our own fruit crops.

In the case of tree planting, it is not the mere comparison of the cost of the excavation of the hole in which to place the tree which has to be considered. When an explosive is

employed, the soil is shaken up and fissured for a comparatively wide area beyond the hole actually required for the tree. When, as often happens, there is a hard and impervious subsoil beyond the reach of the spade, this is also opened and fissured, and experience has shown that trees planted in ground prepared by explosives make a much more vigorous and rapid growth then when planted in the ordinary way. Some trees have begun bearing after four years, while others



Explosives in Agriculture.

similarly situated but spade planted did not yield fruit till six years.

In the case of existing orchards little can be done in the ordinary way to aerate or render the soil more pervious to the roots and moisture, but a small cartridge inserted at some depth below the tree, or a larger one exploded at a depth of 3 feet or so below the surface and midway between trees planted about 15 feet apart, has a most beneficial effect in

loosening the soil without injuring the trees. The roots have less resistance to overcome, the soil is aerated, the moisture retaining properties improved, and a new lease of life is thus given to an old orchard : the trees become more vigorous and productive and indeed are rejuvenated.

The evidence as to the good effects of the judicious use of explosives in this respect is overwhelming in America and some of the colonies; it will no doubt be still more convincing to be able to show improvements obtained in this country.

With this object in view, I am starting some experiments in orchards, and fully expect to get excellent results in due course.

The amount of blasting explosives, excluding cordite, smokeless powder, sporting ammunition, etc., manufactured in this country is about 17,500 tons per annum. Of this amount, about 7,800 tons are sold in the United Kingdom and 9,700 tons are exported to the various markets of South America, Africa, Asia and Australia.

Nobel's factory at Ardeer, in Scotland, is the largest in the world; it covers about 850 acres, employs about 1,800 men and 700 women, and the total output of all kinds of high explosives is between 15,000 and 16,000 tons per annum.

I think it will be evident from what has been already said that chemistry is the foundation of the explosive industry and that the chemist is called upon to fulfil a most important and responsible *rôle* in connection with it, not only in testing and in the research involved in trying new compounds and mixtures, but also in finding out about the vagaries and anomalies in the behaviour of existing explosives.

A glance at the composition of many of the mixtures which have been proposed in patents and submitted to the Home

Office shows the most amazing collection of ingredients. which suggest the contents of a witches' cauldron rather than the well reasoned results of theoretical considerations or experiments ; and as there are many explosives on the authorised list of extreme complexity, there is no lack of opportunity for the exercise of the highest analytical skill when they have to be examined.

There is an enormous number of combinations which can be made of oxygen-yielding and carbonaceous or nitro-aromatic compounds which will explode, but not all of them are suitable or safe enough for practical purposes, and the manufacturer who is asked to adopt them, or the consulting chemist whose advice is sought in this connection, has ample opportunity for exercising all the chemical and physical knowledge and skill he can command. Much investigation has been done on the nitration of celluloses, but many points are still obscure and require further elucidating. Nitrocellulose is indefinite in character, and it will be a relief to all who work with and have the care of explosives if it is ever entirely replaced by a really stable body. Meantime, there is plenty of work to be done to find out the cause of the exudation of nitroglycerine from gelatinous explosives and the loss of sensitiveness which sometimes occurs, especially when they have been kept for long in hot climates.

The chemical control of the manufacture is naturally much more intricate and extensive in the case of nitroglycerine and nitrocellulose than when the manufacture consists in mixing several ready-made ingredients, but even in the latter circumstances difficulties are continually cropping up which call for chemical investigation. The preparation of explosives which will pass the permitted test if attempted without chemical knowledge is truly a beating of the air and waste of time.

In the larger explosive works and in the Government establishments, there are research departments where investi-

gations are always in progress and the properties of new bodies are being studied. The work is intensely interesting: to have such concentrated energy, as it were, in one's hand, to understand it in a measure, to be able to control it, and make it work as one wants, is surely fascinating. In few industries is there such necessity for a high ideal of conduct and conscientious carrying out of work and maintenance of discipline as in an explosive factory. Carelessness or a mistake may risk one's own life as well as that of others. Assuming the necessity for the preparation of war material, surely it is a worthy aim to see that it is of the best quality and most honest manufacture, so that it explodes only when wanted; and with blasting explosives, it is a noble endeavour to make them as safe as possible in manufacture and in use and to lessen as far as possible the risk of causing an explosion of gas or dust in coal mines.

I have only attempted to give a sketch of this vast subject, and hope that I may have succeeded in giving a little insight into it and stimulating the interest of some of the younger men in one of the most interesting fields of chemical activity.

A number of lantern slides kindly lent by Sir Frederic Nathan, The Cotton Powder Co., and Mr. Mathesius, of the Dupont Powder Co., were shown illustrating the manufacture of explosives and their use for tree planting and agricultural purposes.

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LIST OF EXHIBITS.

Samples of blasting and military explosives (Messrs. Curtis's & Harvey: The Cotton Powder Co.).

Detonators, safety fuses, instantaneous, and detonating fuses, volley firers, and igniting devices (Messrs. Bickford, Smith & Co.).

Heat test apparatus, and P. & F. Dupre's constant temperature regulator.

Dupré's vapour pressure apparatus for measuring rate of decomposition of nitrocellulose.

Robertson's apparatus for measuring rate of decomposition of nitroglycerine.

Berthelot calorimetric bomb.

Bomb with crusher gauge.

Small Trauzl lead blocks for testing detonators.

Lead cylinders for "brisance" test, before and after use.

Samples of nitrocellulose of high and low nitration, and solutions of different degrees of viscosity.

Sample of "insoluble" highly nitrated guncotton, gelatinised by ether-alcohol at low temperature.

"Silver vessel test" apparatus for testing cordite (Messrs. Baird & Tatlock).

Blocks and cartridges of trinitrotoluol copper plated for military use (Explosives Loading Co.).

Tetranitroaniline, in powder, also compressed cartridge (Dr. Flurscheim).

Bomb for dropping from aeroplane, rifle grenade, illuminating grenade (The Cotton Powder Co.).

Panoramic photograph of Nobel's Ardeer Works.

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